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# 大兴安岭南段罕苏木地区二长花岗岩锆石 U-Pb 年龄、Hf 同位素特征及其伸展构造作用

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**摘要:**大兴安岭南段罕苏木地区出露大面积的二长花岗岩,为了正确认识该岩体的形成时代及其伸展构造作用,本文采集相关样品,对罕苏木地区出露的二长花岗岩体开展了岩相学、LA-MC-ICP-MS 锆石年代学和 Hf 同位素分析研究。研究表明:罕苏木地区二长花岗岩岩性为微细粒斑状含角闪黑云二长花岗岩和细粒斑状含黑云二长花岗岩,具有斑状和似斑状结构,块状构造。二长花岗岩中的锆石为岩浆成因,测得  $^{206}\text{Pb}/^{238}\text{U}$  年龄的加权平均值为  $(136\pm 1)\text{Ma}$  (MSWD=1.4),属于早白垩世晚期岩浆活动的产物。这一结果与研究区及周边,甚至是与区域上中国东北地区 114~145 Ma 岩浆活动相吻合,都属于同一岩浆活动阶段的产物。罕苏木地区二长花岗岩锆石的  $\varepsilon_{\text{Hf}}(t)$  值均为正值,变化范围为 7.1~14.4,并且具有较年轻的二阶段模式年龄,  $T_{\text{DM2}}$  为 324~959 Ma。年轻的 Hf 同位素模式年龄,暗示在新元古代—晚古生代曾发生一次重要的地壳增生事件。结合区域地质,表明研究区二长花岗岩的岩浆可能是来源于从亏损地幔中新增生的年轻地壳发生部分熔融的产物,在侵位过程中受到了地壳或岩石圈地幔的混染,可能形成在造山后岩石圈伸展环境下,与古太平洋板块向欧亚大陆俯冲有关。

**关键词:**二长花岗岩; 锆石 U-Pb 年龄; Hf 同位素; 伸展构造; 大兴安岭; 地质调查工程

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## Zircon U-Pb ages, Hf isotope and extensional tectonics of monzogranite in the Hansumu area of southern Great Khingan

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**Abstract:** Large area of monzogranite is outcropped in the Hansumu area of southern Great Khingan. In order to recognize the formation age of the rock and its tectonic significance, samples were collected from the monzogranite pluton to study its petrography, zircon LA-MC-ICP-MS age and Hf isotope. The results show that the pluton is composed of fine-grained porphyritic amphibolite-biotite monzogranite and fine-grained porphyritic biotite monzogranite with porphyritic and porphyritic structures and massive structures. The zircons from the monzogranite is of magmatic origin, and yields  $^{206}\text{Pb}/^{238}\text{U}$  age of  $136\pm 1$  Ma (MSWD=1.4), which suggests that the pluton was formed in the late Early Cretaceous. This result is strongly consistent with the study area and its surrounding areas, and even with the 114–145 Ma magmatic activities in the northeastern of China, indicating the products of the same magmatic activity stage. The monzogranite in the Hansumu area has positive  $\epsilon_{\text{Hf}}(t)$  values of 7.1 to 14.4 and young Hf two-stage model ages, and  $T_{\text{DM2}}$  is 324 to 959 Ma. Young Hf isotope model ages imply that this area could have experienced an important crustal accretion event during the Neoproterozoic–Late Proterozoic. Combined with regional geology, it is suggested that the monzogranite was likely derived from the partial melting of young mantle, and possibly was formed in a lithosphere extensional tectonics environment related to the subduction of the Paleo-Asian plate to Eurasia Plate.

**Key words:** Monzonitic granite; zircon U–Pb ages; Hf isotopic; extensional tectonics; Great Khingan; geological survey engineering

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## 1 引 言

大兴安岭是重要的成矿区,也是研究中国中生代构造岩浆演化的重点地区之一,它的大地构造位置是在中亚造山带的东段(Sengor et al., 1993),区域上发育有 114~145 Ma、170~200 Ma、240~270 Ma、310~340 Ma、475~505 Ma 五期比较重大的花岗质岩浆活动(Wu et al., 2011; Wang et al., 2017),其中主要发育有晚古生代和早白垩世两个阶段的花岗岩体(Wu et al., 2011; 张兴洲等, 2012; 李猛星等, 2020; 贺虫云等, 2020)。在中生代时期,区域上西伯利亚板块与华北板块发生碰撞,同时经历了蒙古—鄂霍茨克构造体系与环太平洋构造体系的叠加和改造(吴福元等, 2003; 孟恩等, 2011; Zhang et al., 2019),以及后期的巨型地壳伸展(Wang et al., 2011)和大规模的岩浆事件(吴福元等, 2003; 绍济安等, 2005)。大兴安岭南段岩浆作用十分发育,孕育出了丰富的矿产资源(图 1b)(欧阳荷根等, 2013),主要发育有燕山期和海西期的花岗岩体(张德全等, 1993; Jahn et al., 2000)。在大兴安岭南段罕苏木地区出露有大面积的二长花岗岩岩体,经过前人开展的大量研究,积累了一定的基础资料和数据,然而对该岩体的形成时代及岩性特征仍然存在争议,有研究认为该地区花岗岩体的形成时代为白垩

纪(燕山晚期),岩性为黑云母花岗岩<sup>①</sup>;还有研究测得该花岗岩体的锆石 U–Pb 年龄为 236.8 Ma,岩性为粗中粒花岗闪长岩,认为形成时代为中三叠世<sup>②</sup>。为了正确认识该花岗岩体的形成时代和构造意义,本文采集了相关样品,开展了岩石岩相学特征、Hf 同位素以及锆石 U–Pb 年代学研究,探讨了其形成时代与构造意义,为深入了解大兴安岭南段岩浆活动及构造事件提供依据。

## 2 区域地质概况

研究区位于大兴安岭南段,大地构造位置是位于大兴安岭的新华夏系构造带的南部。大兴安岭南段主要由松嫩地块、兴安地块和额尔古纳地块组成(图 1a)。区域上经历的大地构造演化过程主要有两个阶段:在古生代至早侏罗世时期,位于中亚造山带的东段,在中侏罗世至早白垩世时期,则转入到了陆内的伸展构造体制(Meng et al., 2003; Xiao et al., 2003)。研究区内发育有晚古生代的基底和燕山期的盖层(王晰等, 2018),其中晚古生代基底主要是林西组滨浅海相陆源碎屑岩—碳酸盐建造,海相陆源碎屑岩—火山岩熔岩、火山碎屑岩建造,浅海相陆源碎屑岩泻湖相、湖相陆源碎屑岩建造等。燕山期盖层主要是由陆相的中酸性火山岩组成,发育有塔木兰沟组、满克头鄂博组、玛尼吐

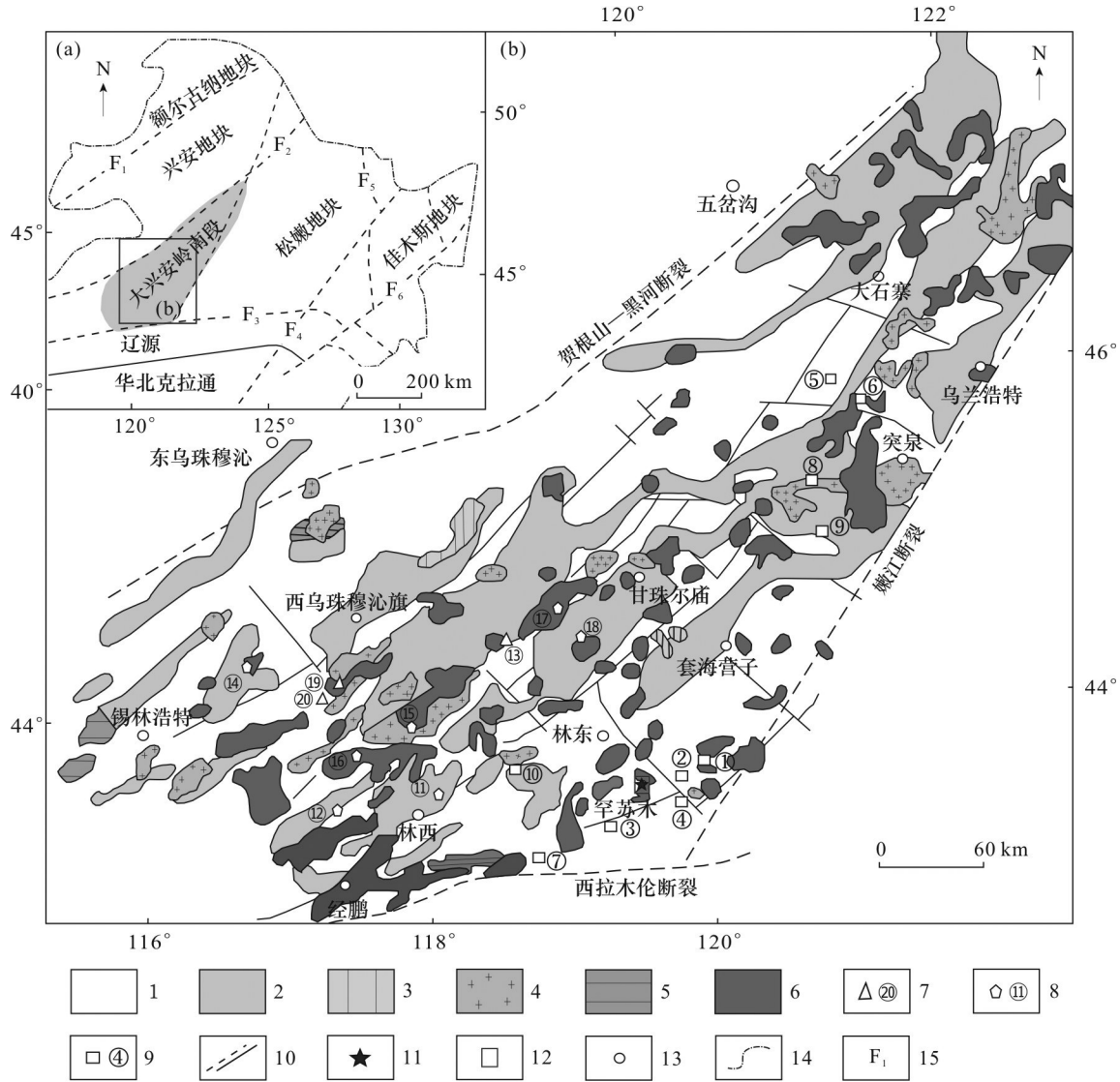


图1 大兴安岭南段大地构造位置图(a)(据吴福元等,2007修改)及岩浆分布与矿产资源略图(b)(据张兴洲等,2012修改)  
 1—中—新生代地层;2—晚古生代地层;3—早燕山期花岗岩;4—海西期花岗岩;5—早古生代花岗岩;6—晚燕山期花岗岩;7—Pb—Zn 矿床及编号;8—Fe—Sn 矿床及编号;9—Cu—Mo 矿床及编号;10—断层;11—罕苏木;12—研究区位置;13—地名;14—国境线;15—断裂(F<sub>1</sub>—塔源—喜桂图断裂;F<sub>2</sub>—贺根山—黑河断裂;F<sub>3</sub>—西拉木伦—长春断裂;F<sub>4</sub>—伊通—依兰断裂;F<sub>5</sub>—牡丹江断裂;F<sub>6</sub>—敦化—密山断裂)区域典型矿床:①—敖仑花;②—半拉山;③—羊场;④—老架沟;⑤—闹牛山;⑥—莲花山;⑦—龙头山;⑧—蒙恩陶勒盖;⑨—布敦化;⑩—敖尔盖;⑪—大井;⑫—黄岗;⑬—白音诺尔;⑭—毛登;⑮—宝盖沟;⑯—查木汗;⑰—浩布高;⑱—敖瑙达巴;⑳—拜仁达坝;㉑—维拉斯托  
 Fig.1 Tectonic location (a) (modified from Wu et al.,2007) and geological map showing distribution of magmatic rocks and mineral resources (b) (modified from Zhang et al.,2012)

1—Middle—Cenozoic;2—Late Paleozoic;3—Early Yanshan granite;4—Hercynian granite;5—Early Paleozoic granite;6—Late Yanshan granite;7—Pb—Zn deposits and numbers;8—Fe—Sn deposits and numbers;9—Cu—Mo deposits and numbers;10—fault;11—Hansumu;12—Research area;13—Place name;14—Border line;15—Fracture (F<sub>1</sub>—Tayuan—Xiguitu fracture;F<sub>2</sub>—Hegenshan—Heihe fracture;F<sub>3</sub>—Xilamulun—Changchun fracture;F<sub>4</sub>—Yitong—Yilan fracture;F<sub>5</sub>—Mudanjiang fracture;F<sub>6</sub>—Dunhua—Mishan fracture) Typical regional deposits: ①—Aolunhua; ②—Banlashan; ③—Yangchang; ④—Laojiagou; ⑤—Naoniushan; ⑥—Lianhuashan; ⑦—Longtoushan; ⑧—Mengentaolegai; ⑨—Budunhua; ⑩—Aoergai; ⑪—Dajing; ⑫—Huanggang; ⑬—Baiyinnuoer; ⑭—Maodeng; ⑮—Baogaigou; ⑯—Chamuhan; ⑰—Haobugao; ⑱—Aonaodaba; ⑲—Bairendaba; ⑳—Weilasituo

组、白音高老组以及梅勒图组。发育的地层有新生代、中生代和古生代地层,并且分布有较大面积的显生宙花岗岩体(赵越等,1994)。区内出露的花岗质岩体主要有早白垩世斜长花岗斑岩、早白垩世二长花岗岩、早白垩世二长花岗斑岩、早白垩世花岗闪长岩、早白垩世花岗斑岩。

本次开展研究的二长花岗岩位于大兴安岭南段的罕苏木地区,行政区划属于内蒙古赤峰阿鲁科尔沁旗的罕苏木乡,花岗岩岩体位于内蒙古天山镇北西约 50 km 小井子幅东南部和罕庙幅西北端一带,呈岩株状产出,总体在区域上呈北东向延伸,出露的面积约 8 km<sup>2</sup>。主体岩性为二长花岗岩,与晚古生代地层表现为侵入接触关系(图 2)。

### 3 样品岩石学特征

#### 3.1 样品描述

样品采自内蒙古赤峰地区阿鲁科尔沁旗罕苏木乡,花岗岩体采样坐标为 44°39'30"N 和 119°45'51"E(图 2),为了避免样品数据结果引起的偶然性,样品在该坐标为中心,在其周围 15~20 m 范围内选取。本次共采集样品 5 件,样品编号为 ZS8YQ1、ZS8YQ2、ZS8YQ3、ZS8YQ4 和 ZS8YQ5,为二长花

岗岩。岩石的新鲜面为浅灰绿色,风化面为黄褐色,斑状和似斑状结构,块状构造(图 3a、b)。

#### 3.2 岩石学特征

通过野外地质观察和显微镜下鉴定,研究区二长花岗岩样品定名为微细粒斑状含角闪石黑云母二长花岗岩和细粒斑状含黑云母二长花岗岩(图 3c、d)。矿物粒度主要在 0.8~11 mm。主要的组成矿物为斜长石、钾长石和石英,黑云母和少量的角闪石为次要矿物组成,副矿物则主要是不透明矿物和磷灰石。次生的矿物有高岭土、粘土、黝帘石、绢云母、绿泥石、铁质。其中,斜长石的含量在 20%~25%,呈半自形板状,分布比较杂乱,发育有环带结构,具有粘土化、局部黝帘石化,常见蚀变矿物沿环带分布;钾长石的含量在 1%~5%,自形—近半自形板状,零星的分布并具有轻微的高岭土化,有的粒内可见斜长石、黑云母包体;石英含量为 5%~10%,半自形粒状,零星分布并具有波状消光,个别粒内可见嵌布斜长石;黑云母的含量约在 5%,片状,星散分布,Ng'呈褐色,Np'呈浅黄褐色,具有多色性,局部显示被绿泥石交代,发育双晶弯曲现象;角闪石的含量则小于 5%,星散分布,半自形柱粒状,绿色。

基质主要包括了斜长石、钾长石、石英还有黑云母,粒径多为 0.1~0.9 mm。其中,斜长石含量 15%~20%,呈半自形的板状,分布杂乱,具有不均匀粘土化、黝帘石化等,环带结构局部发育;钾长石含量为 25%~30%,为半自形的板状—他形粒状,分布杂乱,具有轻微的高岭土化;石英含量约 10%~20%,呈他形粒状,分布杂乱;黑云母的含量比较少,主要呈叶片状,零星分布,多色性和蚀变特征与斑晶一致。

### 4 分析方法

此次样品的破碎以及锆石单矿物的分选是在河北省廊坊的区域地质调查所实验室进行,首先将样品破碎,样品加工至 80~100 目,通过重选以及电磁选的方法来完成分选,最后在双目镜下挑选,主要挑选没有明显的裂痕、晶型比较规则而且透明度又比较好的锆石颗粒。

样品的制靶和锆石的阴极发光图像(CL)、透射光图像以及反射光图像的采集是在天津地质矿产研究所同位素实验室进行。首先挑选有代表性的锆石颗粒,将其固定在环氧树脂的表面,然后抛光

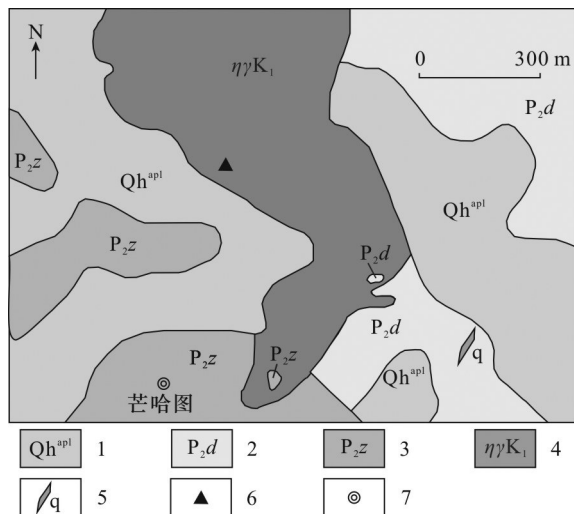


图 2 研究区地质简图

- 1—全新统冲洪积层;2—中二叠统大石寨组;3—中二叠统哲斯组;
- 4—早白垩世二长花岗岩;5—石英脉;6—采样位置;7—地名

Fig.2 Simplified geological map of the study area

- 1—Holocene alluvial layer;2—Middle Permian Dashizhai Formation;
- 3—Middle Permian Zhesi Formation;4—Early Cretaceous monzonitic granite;5—Quartz veins;6—Sample location;7—Place name

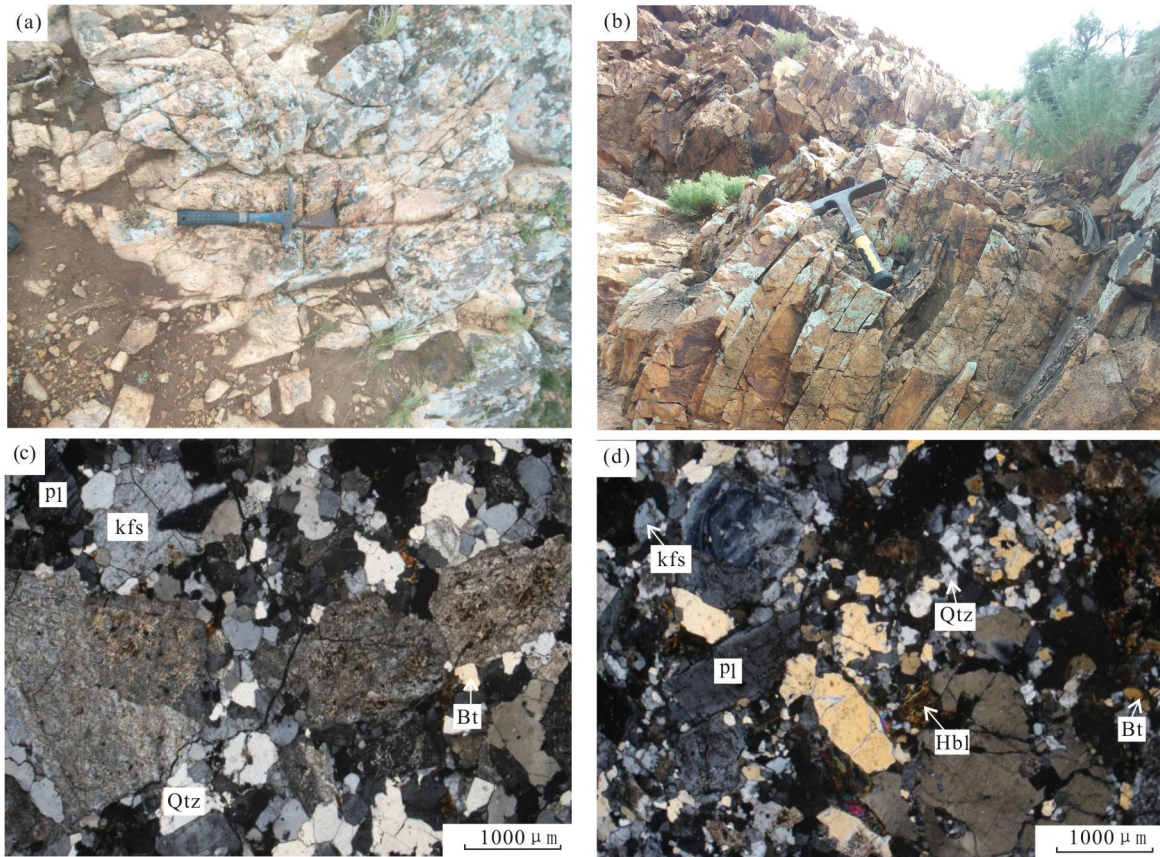


图3 二长花岗岩野外露头(a,b)和镜下照片(c,d)

Pl—斜长石;Kfs—钾长石;Qtz—石英;Bt—黑云母;Hbl—角闪石

Fig.3 Outcrop(a,b) and micrographs(c,d) of monzonitic granite

Pl—Plagioclase; Kfs—Potash feldspar; Qtz—Quartz; Bt—Biotite; Hbl—Common hornblende

打磨,让锆石的表面能够完全暴露,在显微镜下对锆石进行阴极发光拍照以及透射光拍照和反射光拍照,再通过反复的对比阴极发光图像与在显微镜下观察的锆石照片,选择最为合适的锆石颗粒和测试点位,以便获得较可靠的年龄信息。

锆石U-Pb年龄的测定工作是在天津地质矿产研究所同位素实验室完成,主要通过LA-MC-ICP-MS(激光烧蚀多接收电感耦合等离子体质谱仪)完成测定,实验中使用193 nm FX的激光器来对测定的锆石进行剥蚀,分析仪器采用的激光束斑的直径为35 μm,激光剥蚀物质使用He作为载气,测定中采用的外部锆石年龄标准是TEMORA,对Pb、U、Th含量的校正是以NIST612玻璃标样来作为外标,对普通铅进行校正采用的是<sup>208</sup>Pb校正法(Andersen, 2002),详细的分析流程及原理参见李怀坤等(2009, 2010)。对数据的处理主要是利用的ICPMSDataCal程序(Liu et al., 2010)以及Isoplot

(Ludwig, 2003)程序,本次测定的结果和文献中的报道值在误差的范围内完全一致(Black et al., 2003; Yuan et al., 2004; 柳小明等, 2007; 王岚等, 2012)。

锆石原位Lu-Hf同位素分析也是在天津地质矿产研究所同位素实验室完成,在锆石的U-Pb定年分析点上进行同位素Hf分析。同样也是利用激光烧蚀多接收器电感耦合等离子体质谱仪(LA-MC-ICP-MS)完成,通过193 nm FX激光器完成了锆石剥蚀,分析采用的激光束斑的直径为50 μm,采用的锆石GJ-1标准,对Hf同位素以及Yb同位素的比值进行的指数归一化质量歧视校正,分别采用的是<sup>179</sup>Hf/<sup>177</sup>Hf=0.7325(Patchett and Tatsumoto, 1980)和<sup>173</sup>Yb/<sup>172</sup>Yb=1.35274(Chu et al., 2002)。通过对<sup>175</sup>Lu和<sup>172</sup>Yb的测定来对<sup>176</sup>Hf的两个同质异位素<sup>176</sup>Lu和<sup>176</sup>Yb进行干扰校正(Chu et al., 2002);对<sup>176</sup>Yb的同质异位素干扰校正以剥蚀过程中β<sub>Yb</sub>平均值作为Yb的质量歧视校正系数(Iizuka and

Hirata,2005; Wu et al.,2006;侯可军等,2007)。测试分析的流程和原理详细参照耿建珍等(耿建珍等,2011)。 $^{176}\text{Hf}/^{177}\text{Hf}$ 的测定结果与文献报道值在误差范围内完全一致(Gerdes and Zeh, 2006;侯可军等,2007; Yuan et al.,2008)。

## 5 分析结果

### 5.1 锆石U-Pb年龄

研究区二长花岗岩的锆石U-Pb测年的结果详见表1。

样品所测试的锆石多数是无色的,半自形程度较高,具有明显的结晶环带。阴极发光(CL)图(图4)结果显示,锆石颗粒大小约100  $\mu\text{m}$ ,内部结构清晰,长轴和短轴的比值在1:1~2:1,多数的锆石呈短柱状,个别为长柱状,可看到明显的岩浆震荡环带,说明锆石为岩浆成因(张晓飞等,2019)。其中U、Th含量分别为 $259\times 10^{-6}\sim 3314\times 10^{-6}$ 、 $320\times 10^{-6}\sim 3833\times 10^{-6}$ ,平均值分别为 $1944\times 10^{-6}$ 、 $1669.5\times 10^{-6}$ ,Th/U值为0.39~1.24,也显示测定的锆石为岩浆成因(吴元宝等,2004)。本次共选取了24个测点进行U-Pb同位素测定,测得24个测试点的 $^{206}\text{Pb}/^{238}\text{U}$ 年龄为133~

140 Ma,结果显示分析点为成群分布,并且都在谐和线上或位于谐和线附近(图5),测得锆石的 $^{206}\text{Pb}/^{238}\text{U}$ 年龄加权平均值为 $(136\pm 1)\text{Ma}$ (MSWD=1.4),为早白垩世晚期,代表了罕苏木地区二长花岗岩体的侵位年龄。

### 5.2 锆石的Hf同位素组成

罕苏木地区二长花岗岩的Lu-Hf同位素分析结果见表2。

所选测点均在已完成U-Pb测年的锆石样品上进行,对二长花岗岩样品中14颗锆石进行了原位Hf同位素测试。测得二长花岗岩样品 $^{176}\text{Yb}/^{177}\text{Hf}$ 比值为0.065392~0.159326,平均值为0.102606, $^{176}\text{Lu}/^{177}\text{Hf}$ 比值为0.001678~0.003944,平均为0.0025097,基本接近0.002,说明在形成锆石之后由于放射性成因的Hf的积累非常少,所以锆石在形成时的 $^{176}\text{Hf}/^{177}\text{Hf}$ 就可以用初始的 $^{176}\text{Hf}/^{177}\text{Hf}$ 比值来表示,从而利用锆石的 $^{176}\text{Hf}/^{177}\text{Hf}$ 比值探讨岩石形成时的成因(Stille and Steiger,1991;吴福元等,2007)。 $f_{\text{Lu/Hf}}$ 值为-0.88~-0.95,明显低于铁镁质地壳 $f_{\text{Lu/Hf}}$ 值(-0.34)(Amelin et al.,2000),也低于铝质地壳的 $f_{\text{Lu/Hf}}$ 值(-0.72)(Vervoort et al.,1996),因此二阶段的模式年龄也就更能反映

表1 二长花岗岩LA-MC-ICP-MS锆石U-Pb同位素分析结果  
Table 1 LA-MC-ICP-MS zircon U-Pb analytical results of monzonitic granite

测点 编号	含量/ $10^{-6}$			Th/U	同位素比值						表面年龄/Ma					
	Pb	U	Th		$^{206}\text{Pb}/^{238}\text{U}$	$1\sigma$	$^{207}\text{Pb}/^{235}\text{U}$	$1\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$	$1\sigma$	$^{206}\text{Pb}/^{238}\text{U}$	$1\sigma$	$^{207}\text{Pb}/^{235}\text{U}$	$1\sigma$	$^{207}\text{Pb}/^{206}\text{Pb}$	$1\sigma$
1	43	2048	1355	0.66	0.0213	0.0002	0.1421	0.003	0.0485	0.0008	136	1	135	2	123	40
2	52	2259	2720	1.2	0.0209	0.0002	0.1396	0.003	0.0485	0.001	133	1	133	3	122	46
3	44	1974	1630	0.83	0.0214	0.0002	0.1428	0.002	0.0485	0.0006	136	1	136	2	122	30
4	59	2678	2154	0.8	0.0211	0.0002	0.1426	0.002	0.049	0.0006	135	1	135	2	149	28
5	52	2356	2148	0.91	0.0213	0.0002	0.1433	0.002	0.0488	0.0006	136	1	136	2	137	30
6	49	2163	2055	0.95	0.0212	0.0002	0.1423	0.002	0.0487	0.0006	135	1	135	2	132	30
7	39	1771	1487	0.84	0.0212	0.0002	0.1425	0.002	0.0487	0.0007	135	1	135	2	134	32
8	38	1779	2150	1.21	0.0212	0.0002	0.1421	0.002	0.0487	0.0007	135	1	135	2	132	32
9	49	2161	2095	0.97	0.021	0.0002	0.1397	0.002	0.0483	0.0006	134	1	133	2	112	29
10	54	2379	2412	1.01	0.0209	0.0002	0.1395	0.002	0.0485	0.0006	133	1	133	2	125	30
11	78	3314	3833	1.16	0.021	0.0002	0.1409	0.002	0.0486	0.0006	134	1	134	2	126	28
12	44	2054	796	0.39	0.022	0.0002	0.1442	0.003	0.0475	0.0009	140	1	137	3	75	43
13	31	1281	1453	1.13	0.0216	0.0002	0.1436	0.003	0.0482	0.0009	138	1	136	3	108	45
14	31	1403	791	0.56	0.0214	0.0002	0.1426	0.003	0.0483	0.0009	137	1	135	2	113	42
15	67	2861	2706	0.95	0.0211	0.0002	0.1426	0.002	0.049	0.0006	135	1	135	2	147	29
16	66	2801	2478	0.88	0.0213	0.0002	0.142	0.002	0.0484	0.0006	136	1	135	2	121	28
17	30	1347	752	0.56	0.0214	0.0002	0.1425	0.003	0.0483	0.0009	137	1	135	3	112	44
18	38	1686	1219	0.72	0.0212	0.0002	0.1413	0.002	0.0483	0.0007	135	1	134	2	113	33
19	43	1907	1300	0.68	0.0212	0.0002	0.142	0.003	0.0487	0.0007	135	1	135	2	133	35
20	25	1140	578	0.51	0.0214	0.0002	0.1439	0.003	0.0488	0.0008	136	1	136	2	140	39
21	30	1380	795	0.58	0.021	0.0002	0.14	0.003	0.0482	0.0008	134	1	133	2	111	41
22	6	258	320	1.24	0.0216	0.0002	0.1434	0.007	0.0481	0.0024	138	2	136	7	103	117
23	46	1975	1704	0.86	0.0215	0.0002	0.1447	0.002	0.0488	0.0006	137	1	137	2	138	30
24	38	1677	1136	0.68	0.0215	0.0002	0.1447	0.002	0.0488	0.0007	137	1	137	2	139	32

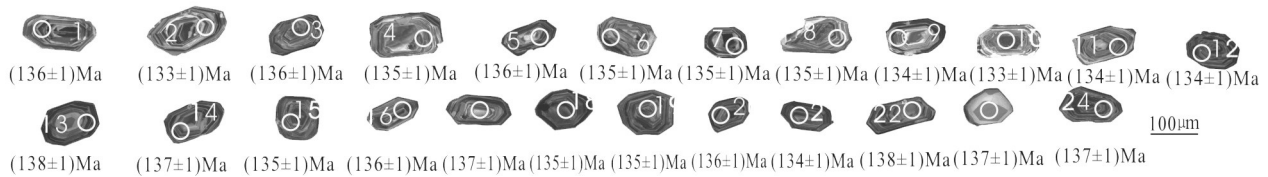


图4 二长花岗岩锆石阴极发光(CL)图像及测点年龄  
Fig.4 Ages and CL images of zircons from the monzonitic granite

出源区物质在地壳的平均存留年龄。测得锆石的  $\epsilon_{\text{Hf}}(t)$  值为 7.1~14.4 (均>0), 平均为 10.0,  $^{176}\text{Hf}/^{177}\text{Hf}$  比值为 0.282897~0.283104, 平均为 0.282976, 二阶段模式年龄  $T_{\text{DM2}}$  (Ma) 为 324~959 Ma, 其加权平均值为 641 Ma。

## 6 讨论

### 6.1 岩体形成时代

大兴安岭南段罕苏木地区的二长花岗岩岩体, 1971年由辽宁省的第二区域地质测量队提交的1:20万协里府幅地质图显示, 该岩体为黑云母花岗岩, 形成时代为燕山晚期(白垩纪); 内蒙古第十地质矿产勘查开发院在2009年实施的项目中认为该岩体为粗中粒花岗闪长岩, 测得锆石的U-Pb年龄为236.8 Ma, 认为该岩体的形成时代为中三叠世。通过本次研究, 测得样品的 $^{206}\text{Pb}/^{238}\text{U}$ 年龄的加权平均值为(136±1) Ma (MSWD=1.4), 所测样品锆石U-Pb数据谐和度都比较好, 结合锆石阴极发光图像和锆石Th/U比值(Th/U>0.40), 锆石为岩浆成因, 因此

该年龄可以代表罕苏木地区二长花岗岩岩体的年龄, 侵位于早白垩世晚期, 即前人厘定的二长花岗岩并非形成于中三叠世。

本次测得的结果和罕庙地区的二长闪长岩测得的锆石U-Pb年龄((134±1) Ma)是一致的(王晰等, 2018), 与研究区相邻的桦杆子沟岩体((136.6±1.1) Ma)(彭青松等, 2017)、哈力黑坝岩体((134.8±1.2) Ma)(江思宏等, 2011)、花加拉嘎岩体((139±1) Ma)、乌兰达坝岩体((139±1) Ma)(杨奇荻等, 2014)和乌兰楚鲁特岩体((139.83±0.82) Ma)(李剑锋等, 2016), 都属于同时期岩浆活动的产物, 岩体成岩时代集中在140~135 Ma(杨奇荻等, 2014; 李剑锋等, 2016), 与区域上中国东北地区114~145 Ma岩浆活动强烈吻合(Wu et al., 2011; 欧阳荷根等, 2013), 与中国东部地区发生的晚中生代岩浆活动时间主要集中在早白垩世的观点也是一致的(王艺龙等, 2019)。

### 6.2 岩浆源区

近年来, 锆石原位Hf同位素分析已经成为解释

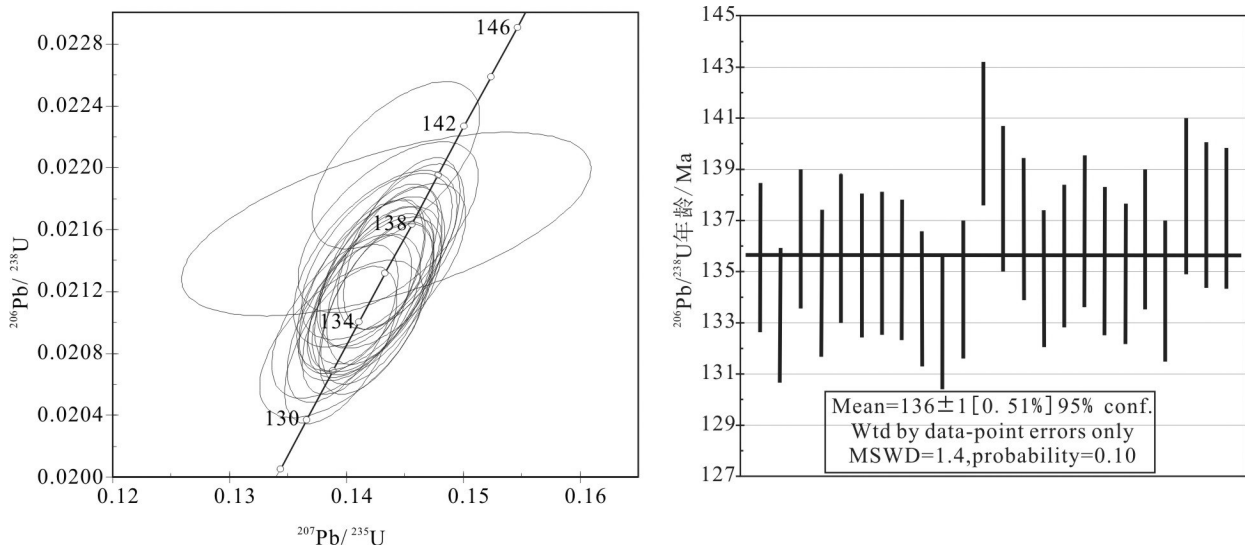


图5 二长花岗岩锆石U-Pb谐和图及 $^{206}\text{Pb}/^{238}\text{U}$ 年龄  
Fig.5 U-Pb Concordia diagram and  $^{206}\text{Pb}/^{238}\text{U}$  ages of zircon in monzonitic granite

表2 二长花岗岩锆石 Hf 同位素分析结果

Table 2 Zircon Hf isotopic data of monzonitic granites

测点号	年龄/Ma	$^{176}\text{Yb}/^{177}\text{Hf}$	$2\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}$	$2\sigma$	$^{176}\text{Hf}/^{177}\text{Hf}_i$	$\varepsilon_{\text{Hf}}(0)$	$\varepsilon_{\text{Hf}}(t)$	$T_{\text{DM1}}/\text{Ma}$	$T_{\text{DM2}}/\text{Ma}$	$f_{\text{LWHF}}$
1	136	0.123788	0.001909	0.003944	0.000042	0.283066	0.000036	0.283056	10.4	13.0	286	447	-0.88
2	133	0.065392	0.001186	0.001678	0.000031	0.282902	0.000025	0.282898	4.6	7.4	505	959	-0.95
3	136	0.117852	0.001915	0.002818	0.000037	0.282921	0.000026	0.282914	5.3	8.0	494	905	-0.92
4	135	0.120470	0.001268	0.002835	0.000024	0.282917	0.000027	0.282909	5.1	7.8	500	921	-0.91
5	136	0.108474	0.001693	0.002709	0.000021	0.283072	0.000029	0.283065	10.6	13.4	266	417	-0.92
6	135	0.106214	0.001925	0.002464	0.000036	0.283026	0.000033	0.283020	9.0	11.7	333	565	-0.93
7	135	0.159326	0.001046	0.003728	0.000042	0.283104	0.000028	0.283095	11.7	14.4	225	324	-0.89
8	135	0.056574	0.001550	0.001529	0.000037	0.282939	0.000030	0.282935	5.9	8.7	450	837	-0.95
9	134	0.126747	0.001967	0.002918	0.000037	0.283004	0.000037	0.282997	8.2	10.9	370	641	-0.91
10	133	0.113756	0.000550	0.002564	0.000013	0.282897	0.000030	0.282891	4.4	7.1	526	983	-0.92
11	134	0.071690	0.001689	0.001730	0.000033	0.282984	0.000023	0.282980	7.5	10.3	388	696	-0.95
12	140	0.093361	0.000564	0.002171	0.000008	0.282967	0.000033	0.282961	6.9	9.8	417	746	-0.93
13	138	0.086973	0.002028	0.002031	0.000038	0.282933	0.000025	0.282928	5.7	8.5	465	856	-0.94
14	137	0.085875	0.001304	0.002017	0.000025	0.282935	0.000028	0.282930	5.8	8.6	462	851	-0.94

地壳演化以及示踪岩浆源区的一种有效的方法手段 (Vervoort and Patchett, 1996; Scherer et al., 2000; Zhang et al., 2012)。Amelin et al. (1999) 认为花岗岩锆石的  $\varepsilon_{\text{Hf}}(t) > 0$ , 说明岩浆是来源于亏损地幔或者是来源于从亏损地幔中新增生的年轻地壳,  $\varepsilon_{\text{Hf}}(t)$  接近于当时地幔值, 花岗岩锆石  $\varepsilon_{\text{Hf}}(t) < 0$ , 说明岩浆是来源于古老的地壳发生重熔。本次测得样品的  $^{176}\text{Hf}/^{177}\text{Hf}$  比值为 0.282897~0.283104, 变化不明显, 说明锆石 Hf 同位素组成比较单一, 其岩浆源区也比较单一。锆石的  $\varepsilon_{\text{Hf}}(t)$  值是 7.1~14.4 (均  $> 0$ ), 平均为 10.0,  $T-\varepsilon_{\text{Hf}}(t)$  图解 (图 6) 可以看出, 所测样品基本都在亏损地幔演化线的附近分布。测得样品的二阶段模式年龄  $T_{\text{DM2}}$  值为 324~959 Ma, 暗示其岩浆源区为亏损地幔的年轻地壳物质, 也暗示在新元古代—晚古生代发生过重要的地壳增生事件。 $\varepsilon_{\text{Hf}}(t)$  值变化区间范围比较大, 显示出不均一性, 造成不均一性的原因有可能是由于来源于地壳物质的混杂或岩石圈地幔物质的混染作用 (Zhu et al., 2011; 周振华等, 2012)。

罕苏木地区的二长花岗岩属于高钾钙碱性 I 型花岗岩, 具有高硅, 富铝富钾, 相对轻稀土富集, 重稀土亏损的特征, 也表明岩浆源区有可能来源于地壳物质的部分熔融 (刘芳等, 2019)。此外, 据已有的资料显示, 大兴安岭南段黄岗地区早白垩世花岗岩体  $\varepsilon_{\text{Hf}}(t)$  值为 +3.5~+18.3,  $T_{\text{DM2}}$  为 561~795 Ma (周振华等, 2010); 黄岗梁地区早白垩世花岗岩体  $\varepsilon_{\text{Hf}}(t)$  为 +1.9~+8.3,  $T_{\text{DM2}}$  为 888~561 Ma (赵辉等, 2015); 白音查干早白垩世岩体  $\varepsilon_{\text{Hf}}(t)$  为 +8.2~+11.6,  $T_{\text{DM2}}$  为 670~450 Ma

(姚磊等, 2017); 甘珠尔庙地区早白垩世小井子岩体的  $\varepsilon_{\text{Hf}}(t)$  值为 +5.8~+13.9,  $T_{\text{DM2}}$  为 302~821 Ma, 花加拉嘎岩体的  $\varepsilon_{\text{Hf}}(t)$  值为 +2.9~+7.9,  $T_{\text{DM2}}$  为 688~1005 Ma, 乌兰达坝岩体的  $\varepsilon_{\text{Hf}}(t)$  值为 +5.6~+13.8,  $T_{\text{DM2}}$  为 310~836 Ma, 巴里木哈德岩体  $\varepsilon_{\text{Hf}}(t)$  值为 +3.4~+8.1,  $T_{\text{DM2}}$  为 663~968 Ma (杨奇荻等, 2014)。这些岩体都具有相似的正  $\varepsilon_{\text{Hf}}(t)$  值, 并且具有年轻的二阶段模式年龄, 表明罕苏木地区的花岗岩体和大兴安岭南段分布的早白垩世花岗岩的岩浆源区具有相似的特征。通常大兴安岭地区发育的显生宙以来的花岗岩的源岩  $\varepsilon_{\text{Hf}}(t)$  都为正值, 同时具有较低的  $T_{\text{DM}}$  值, 中生代的花岗岩与来源于地幔的年轻的地壳物质有关 (洪大卫等, 2000; 林强等, 2004)。

因此, 表明罕苏木地区二长花岗岩可能是来源于亏损地幔中新增生的年轻地壳发生部分熔融的产物, 可能受到了地壳物质的混杂或岩石圈地幔物质的混染。

### 6.3 构造背景

从区域大地构造分析可知, 在晚古生代—中生代期间, 研究区经历了两个构造演化阶段, (1) 晚古生代二叠纪中晚期到三叠纪中期, 华北板块与西伯利亚板块碰撞拼合, 同时古亚洲洋发生闭合, 形成了基本构造格架 (刘伟等, 2003, 2007; Davis et al., 2004; Li, 2006; 李锦轶等, 2007; 周成林等, 2019; 丁坤等, 2020)。(2) 在中生代时期, 陆缘活化型构造和岩浆活动强烈, 大规模成矿 (张德全和赵一鸣等, 1993; 王长明等, 2006; 张永正等, 2007)。晚侏罗世到早白垩世期间, 因为古太平洋板块的俯冲作用,



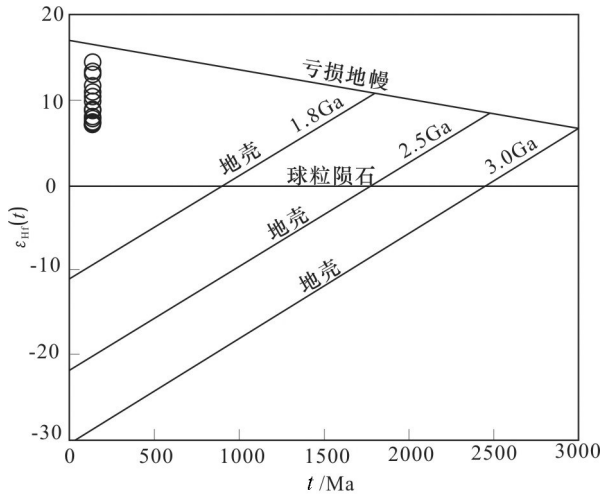


图6 二长花岗岩 Hf 同位素特征(据 Yang et al.,2006)  
Fig.6 Hf isotopic compositions of monzonitic granite(after Yang et al.,2006)

区域构造应力场方向发生改变,由挤压向伸展转换,加厚的地壳发生拆沉作用,地幔物质上涌底侵下地壳发生部分熔融,引发大兴安岭地区的岩浆事件(邵济安等,1999a,1999b;王艺龙,2019)。前人的大量研究成果也证明,该区在早白垩世处于伸展构造环境(邵济安等,2005;张连昌等,2007;许文良等,2013)。而罕苏木地区二长花岗岩的形成时代为早白垩世晚期,显然是属于非造山环境,区域上与早白垩世晚期古太平洋板块发生俯冲作用于欧亚大陆之下而形成的弧后伸展环境有关(许文良等,2013)。

大兴安岭地区是受到何种成岩动力学作用而导致的伸展作用,前人主要有地幔柱观点(葛文春等,1999)、蒙古—鄂霍茨克海闭合观点(Fan et al.,2003;Ying et al.,2010),还有古太平洋板块的俯冲作用等观点(Zhang et al.,2003,2010)。前人在岩相学、年代学、古生物、地球物理、增生杂岩等方面进行了大量的研究,结果表明可能主要与古太平洋板块发生俯冲作用后形成的陆内伸展作用相关(Hilde et al.,1977;Maruyama,1997;张晓东等,2000;Zhang et al.,2008;Xu et al.,2013)。Maruyama(1997)对海底的磁异常条带进行了研究,表明古太平洋板块是在120~150 Ma斜向向欧亚大陆开始发生俯冲作用。同时大兴安岭地区的早白垩世花岗岩呈NNE、NE向分布(孙德有等,1994,2001;邵济安等,1999a;葛文春等,2005),不同于蒙古—鄂霍茨克缝合的分布方向,而基本上和古太平洋板块的俯

冲边缘是一致的,也说明大兴安岭地区早白垩世花岗岩可能是受到了太平洋板块的俯冲作用的影响。

综合分析,本文认为罕苏木地区的二长花岗岩是形成于造山后的伸展环境下,来自幔源的物质上涌,并伴随岩浆底侵作用,导致上覆地壳发生部分熔融,为花岗岩的形成提供了物质来源。因此,罕苏木地区二长花岗岩是伸展背景下岩浆活动的产物,主要与古太平洋板块俯冲欧亚大陆有关。

## 7 结论

(1)大兴安岭南段罕苏木地区出露有大面积的二长花岗岩,为微细粒斑状含角闪黑云二长花岗岩和细粒斑状含黑云二长花岗岩,斑状和似斑状结构,块状构造。斑晶主要是由斜长石(20%~25%)、钾长石(1%~5%)、石英(5%~10%)、黑云母(3%~5%)及少量角闪石组成。

(2)锆石 U-Pb 年龄测试结果显示,罕苏木地区二长花岗岩的  $^{206}\text{Pb}/^{238}\text{U}$  年龄加权平均值为  $(136\pm 1)\text{Ma}$  (MSWD=1.4),即侵位于早白垩世晚期。这一结果与研究区及周边,甚至是与区域上在114~145 Ma中国东北地区的岩浆活动强烈相吻合,属于同一岩浆活动阶段的产物。

(3)罕苏木地区二长花岗岩的岩浆可能来源于从亏损地幔中新增生的年轻地壳发生部分熔融的产物,受到了地壳物质或岩石圈地幔物质的混染;具有年轻的 Hf 同位素模式年龄,暗示在新元古代一晚古生代期间发生了地壳增生事件;花岗岩形成在造山后岩石圈伸展环境下,主要与古太平洋板块俯冲欧亚大陆有关。

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## 注释

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